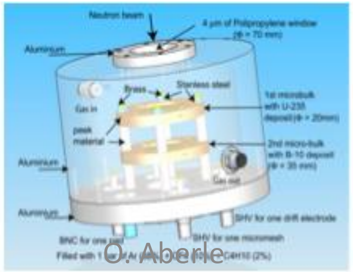
The n_TOF Collaboration,
http://www.cern.ch/nTOF

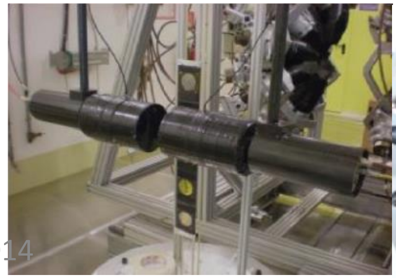
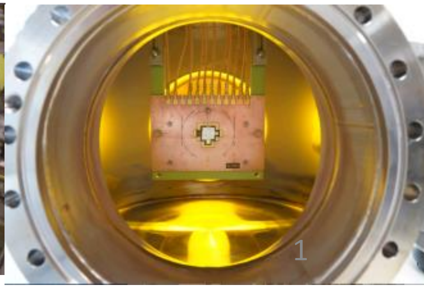
Overview of CERN n_TOF

O. Aberle,

on behalf of Enrico Chiaveri - Spokesperson

of the n_TOF Collaboration



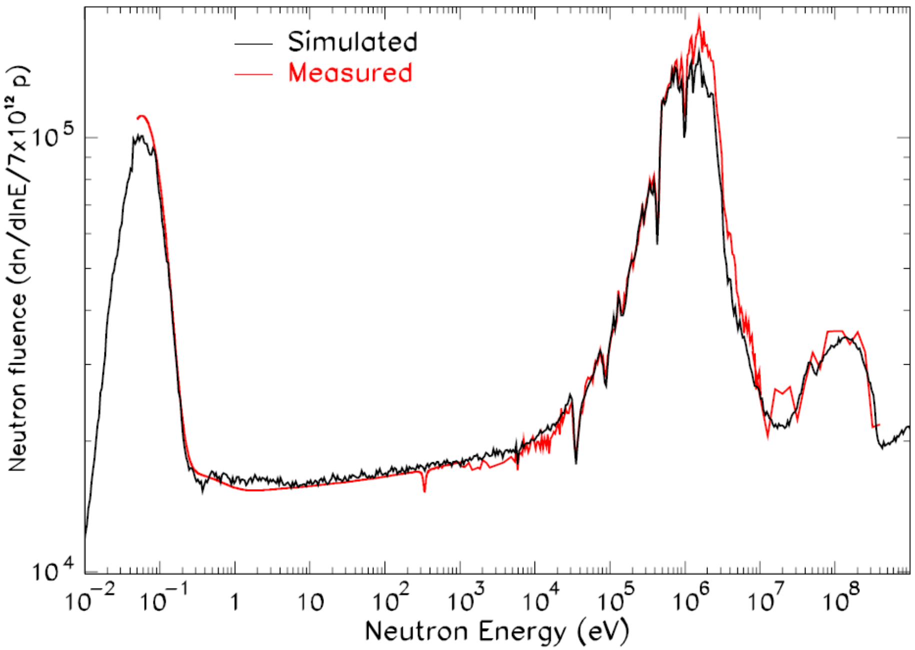




The n_TOF Facility

The goal of the n_TOF is to provide unprecedented precision in neutron kinetic energy determination, which will in turn bring much-needed precision in neutron-induced cross-section measurements. Such measurements are vital for a range of studies in fields as diverse as nuclear technology, astrophysics and fundamental nuclear physics. The n_TOF will provide neutron rates some three orders of magnitude higher than existing facilities, allowing measurements to be made more precisely and more rapidly than in the past.

CERN COURIER
Jul 2, 2001

The n_TOF facility since 2001



- Main feature of n_TOF is the extremely high instantaneous neutron flux (10^5 n/cm^2/pulse)
- Unique facility for measurements of radioactive isotopes (maximize S/N)
  - Branch point isotopes (astrophysics)
  - Actinides (nuclear technology)

- Other features of the neutron beam:
  - High resolution in energy ($\Delta E/E=10^{-4}$) → study resonances
  - Large energy range (25 meV<E_n<1 GeV) → measure fission up to 1 GeV
  - Low repetition rate (<0.8 Hz) → no wrap-around

n_TOF Collaboration Institutions

- n_TOF Collaboration is an international endeavour since 2001
- Members as of 2012 (not necessarily CERN member states):
  - 35 Institutions (EU, USA, India, JP and RUS)
  - 110 scientists
  - 16 PhD students

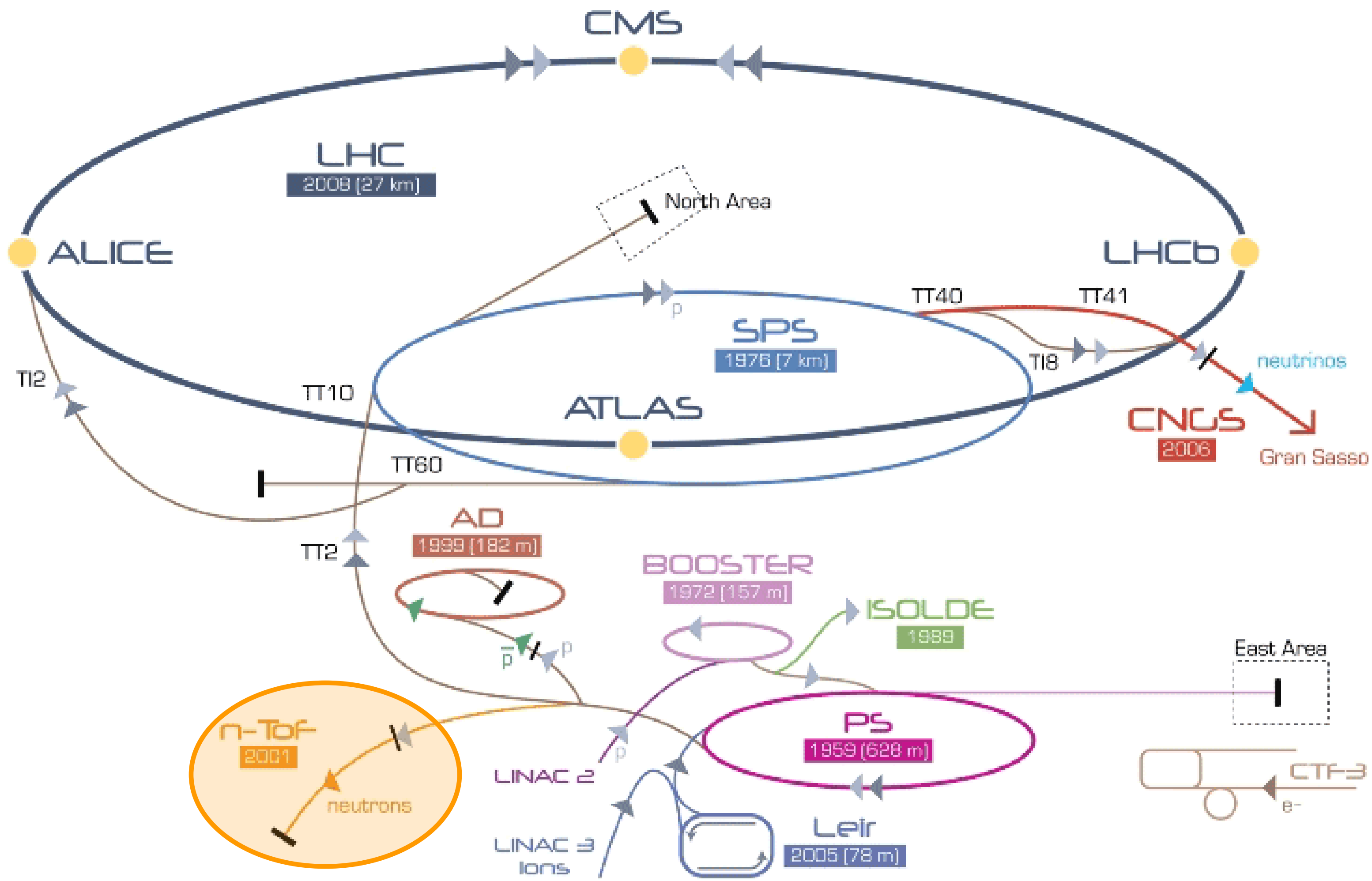
- Newcomers since 2009:
  - Joint Research Center IRMM (Belgium)
  - University of Zagreb (Croatia)
  - University of Manchester (United Kingdom)
  - University of York (United Kingdom)
  - University of Frankfurt (Germany)
  - PSI – Paul Scherrer Institute (Switzerland)
  - University of Thessaloniki (Greece)
  - JINR-Dubna (Russia)
  - IPPE-Obninks (Russia
  - PTB (Germany) →
  - University of Canberra (Australia) →

In consideration for membership

Research fields of interest at n_TOF

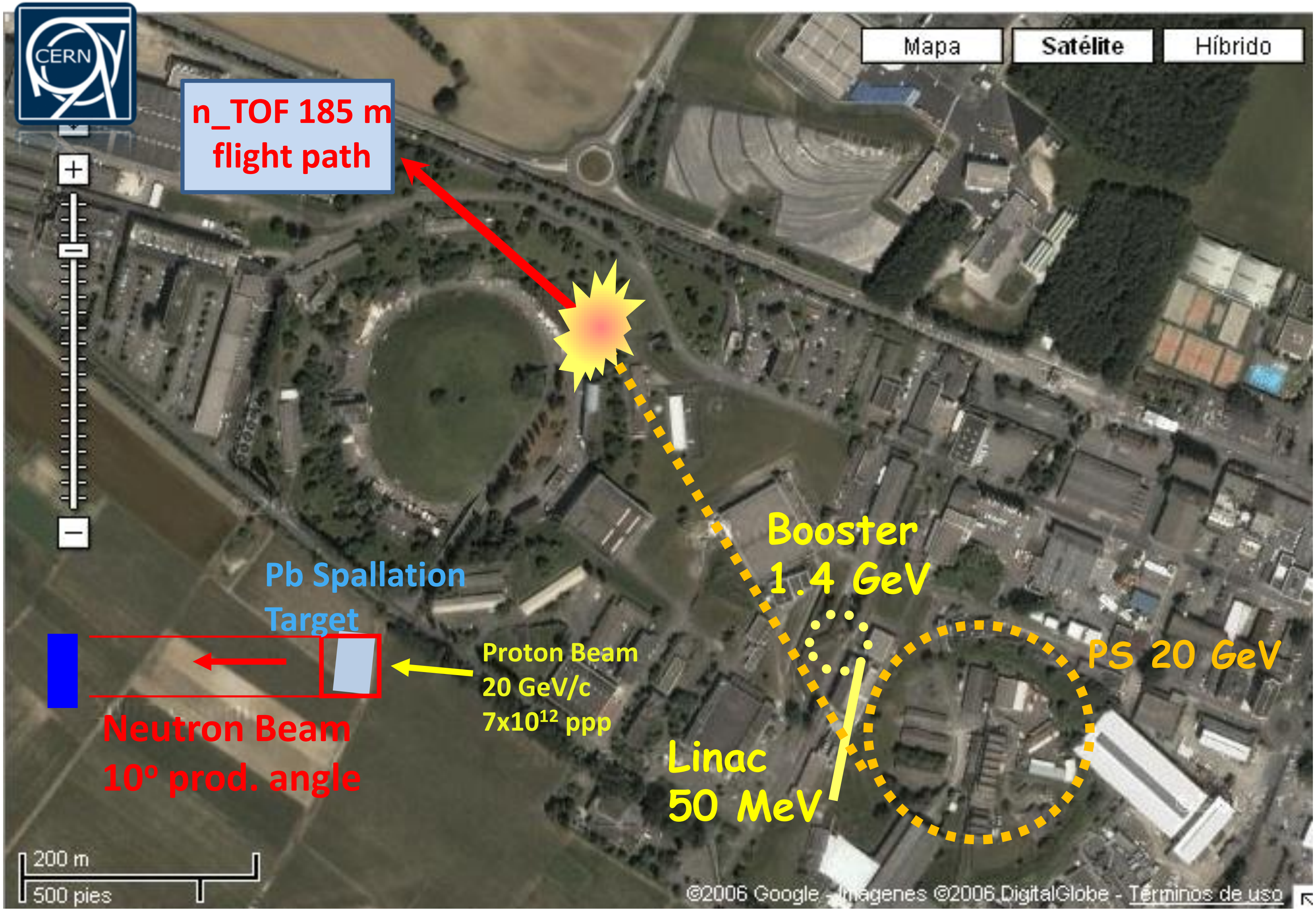
- **Cross-section for Nuclear Technologies**
  - U cycle: $^{235}U_{n,\gamma/f}$(TAC+MGAS), $^{237}Np_{n,f}$ (PPAC), $^{238}U_{n,\gamma}$(TAC), $^{241}Am_{n,\gamma}$ (C_6D_6+TAC)
  - Thorium cycle: $^{232}Th_{n,f}$ (PPAC), $^{236}U_{n,f}$ (C_6D_6+TAC)
- **Cross-section for Stellar Nucleosynthesis**
  - The role of capture on stable Fe/Ni: ^{54,56,57}Fe, ^{58,62}Ni (C_6D_6)
  - First branching of the s-process: $^{63}Ni_{n,\gamma}$ (C_6D_6)
  - (n,α) reaction in the s-process branching point ^{59}Ni (sCVD)
  - Neut. capture cross-section of ^{25}Mg and its astrophysical implications (C_6D_6)
- **Nuclear Medicine**
  - ^{33}S(n,α) reaction for enhancing BNCT for cancer treatment
- **Basic Nuclear Physics**
  - Angular distribution of fission fragments from ^{232}Th, ^{235}U, ^{237}Np and ^{238}U
  - Spin assignment of nuclear levels above S_n in ^{88}Sr (TAC)
  - Test for measurement for INC model benchmarks: (*n,**) reactions above 300 MeV

n_TOF: A spallation neutron source using the PS 20 GeV/c prot. beam

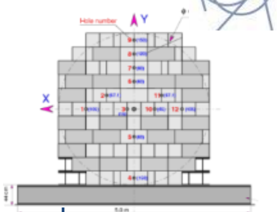


C. Rubbia et al., ***A high resolution spallation driven facility at the CERN-PS to measure neutron cross sections in the interval from 1 eV to 250 MeV***, CERN/LHC/98-02(EET) 1998.

The n_TOF Facility at CERN: a Google view



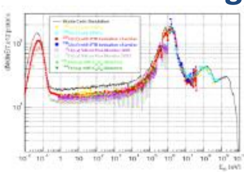
n_TOF Timeline



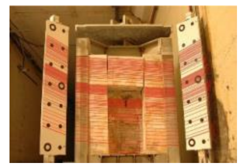
1995-1997 **TARC** experiment

May 1998 **Feasibility** CERN/LHC/98-02+Add

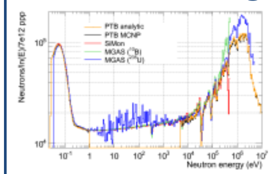
2000 **Commissioning**



2004-2007 **Problem** Investigation



May 2009 **Commissioning**



2010 **Upgrades:**
Borated-H_2O
Second Line
Class-A

July 2014 **Commissioning**

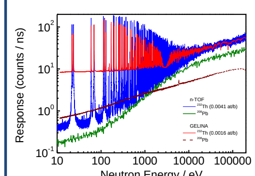
1996 — **2014**

1997 **Concept** by C.Rubbia CERN/ET/Int. Note 97-19

Aug 1998 **Proposal** submitted

1999 **Construction** started

2001-2004



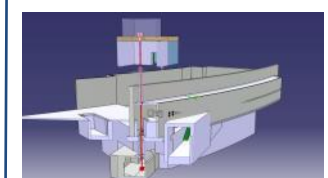
Phase I
Isotopes
Capture: 25
Fission: 11

2008

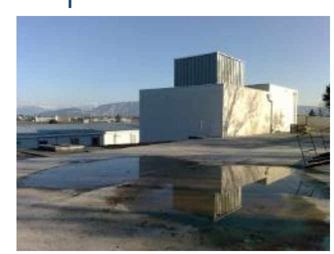
New Target construction

2009 - 2012 **Phase II**
Isotopes
Capture: 14
Fission: 3
(n,cp): 2

2011



EAR2 Design and Construction

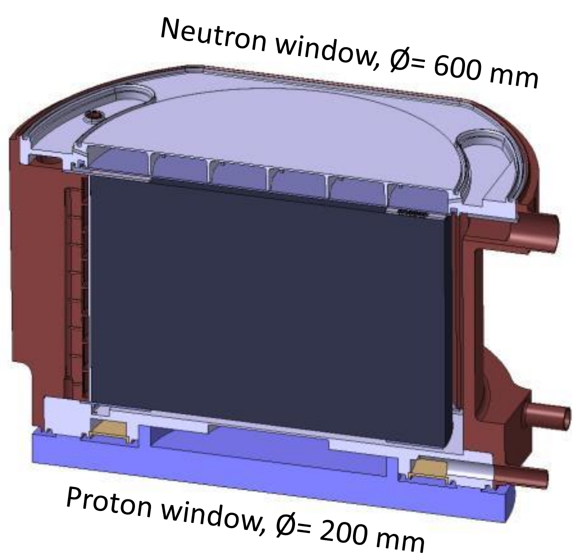


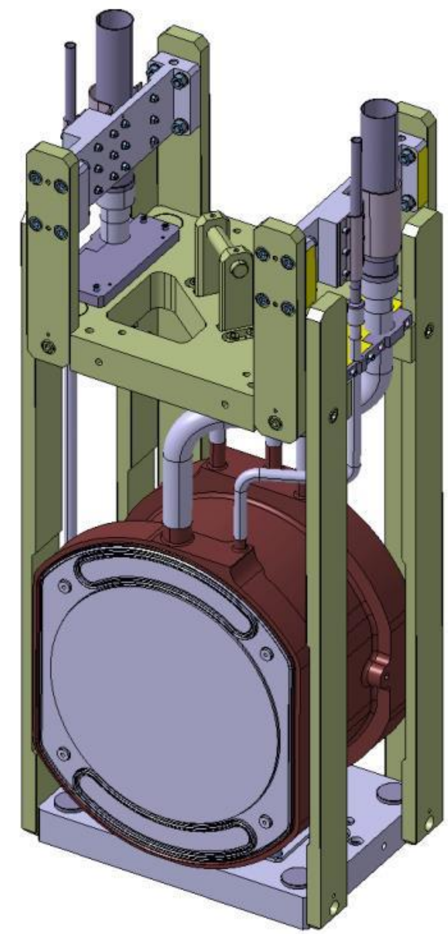
n_TOF facility improvements 2009/2014

1. New lead spallation target [2008/9]
   - Extended operation of n_TOF
2. Improved cooling and ventilation system [2009]
   - Optimization of heat dissipation and water chemistry
3. Separated moderator system: ^{10}B water as moderator [2010]
   - Reduction of the in-beam γ-rays by factor of 10x
4. Transformation of the EAR1 in a type-A laboratory [2010]
   - No need for certified sealing for radioactive samples
5. *Extended memory of flash-ADC digitizers [2011]*
   - *n,γ measurement with C_6D_6 down to thermal energies (25.3 meV)*
6. **Experimental Area 2 Project [2012-2014]**

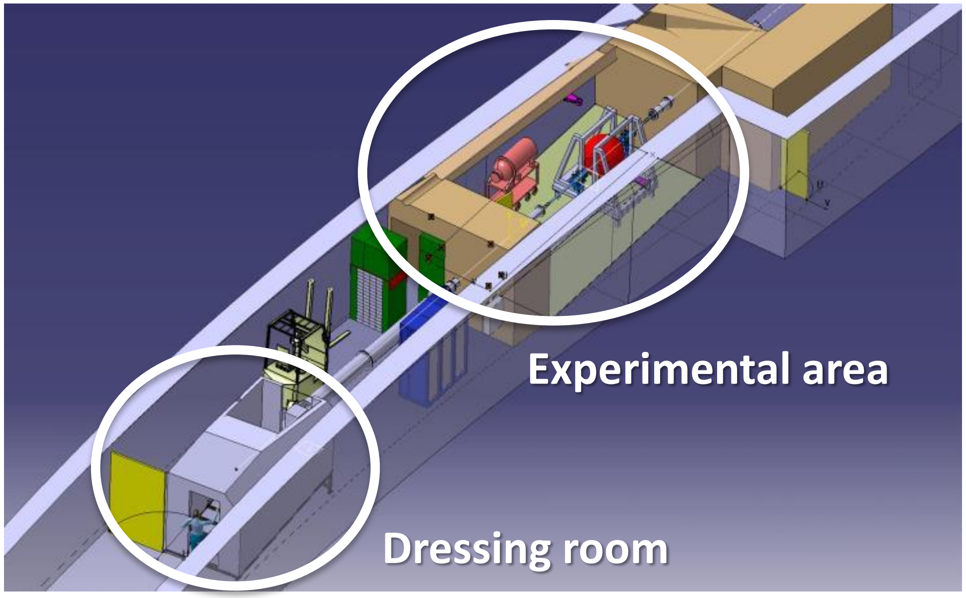
n_TOF new spallation target

- Spallation target is now enclosed in a new pressurized vessel
- Pure lead 99.99% monolithic
- Support and anti-creep structure in AW5083 H111
- Uncladded design
- Water chemistry continuously monitored
- Water jet flow on the proton entrance surface to maintain local temperature less than boiling point





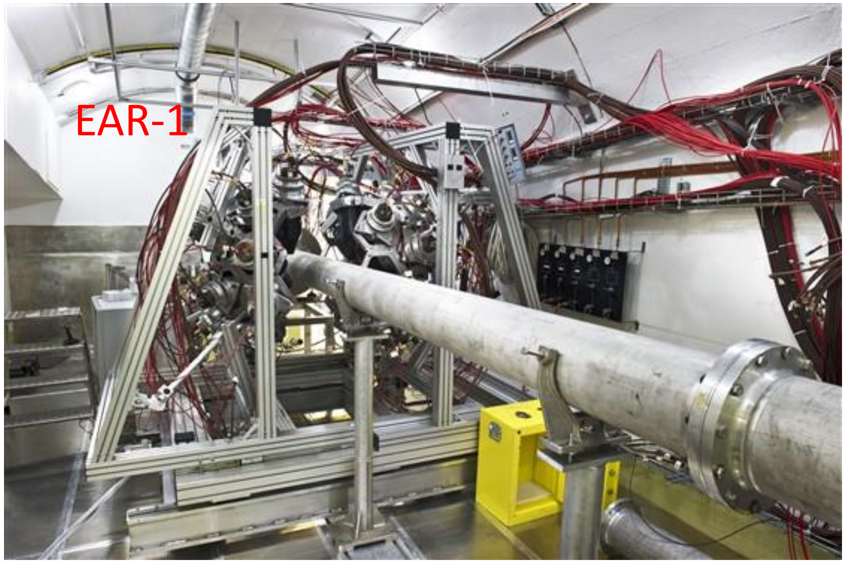
The new experimental area



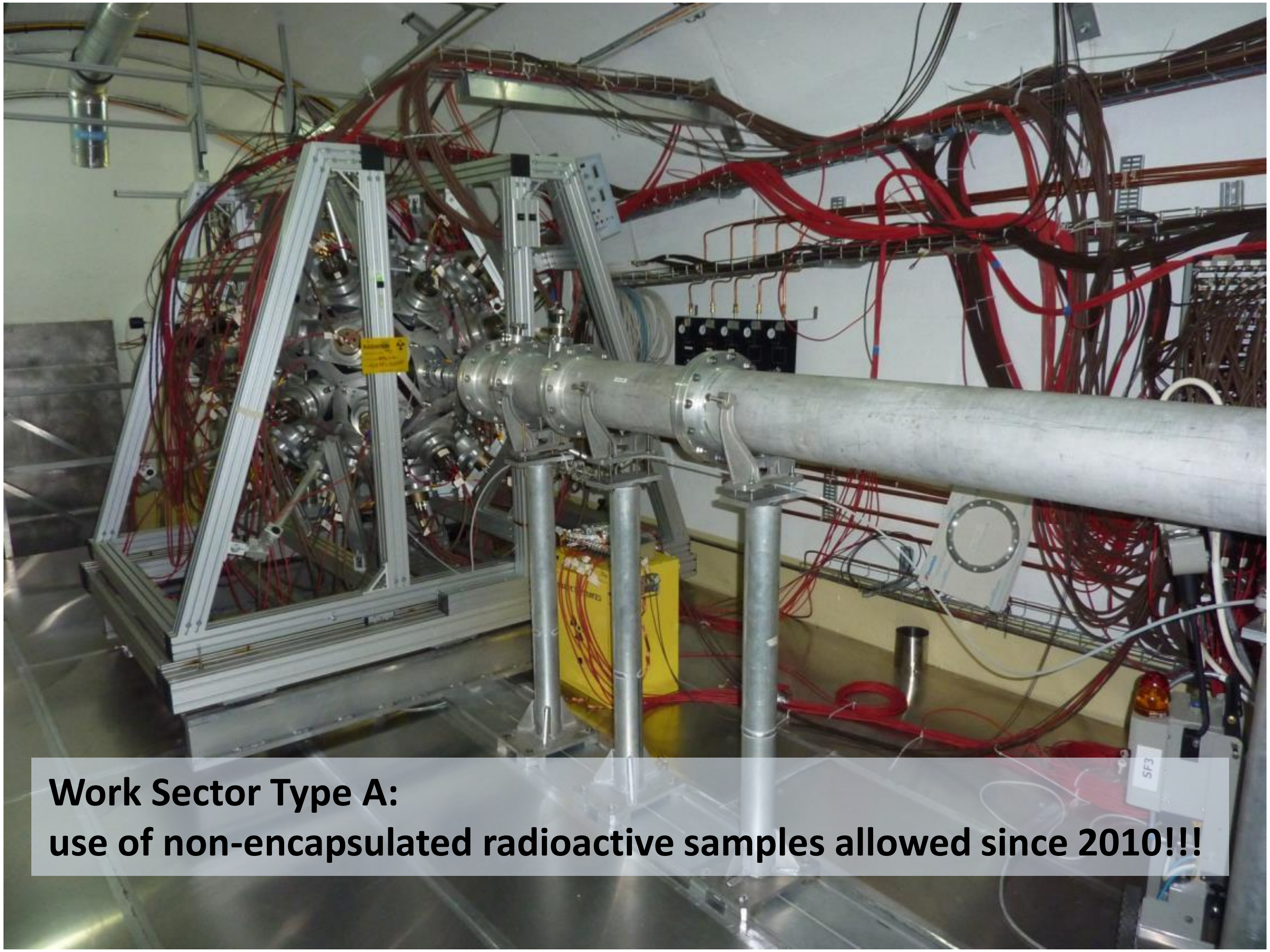
- To measure radioactive isotopes at CERN
  - Encapsulated samples with ISO2919 certification
  - Suitable experimental area ("hot lab") to cope with unsealed samples

- EAR1 transformed in a Work Sector "Type A" adapted to handle **unsealed radioactive samples**
  - Under pressure area, controlled ventilation, fire-proof doors, fire detection system, aerosol contaminant monitors, etc.
- <u>We can measure very radioactive material without canning</u>

N_TOF Beam Line



The n_TOF Facility in pictures



Work Sector Type A:
use of non-encapsulated radioactive samples allowed since 2010!!!

The n_TOF Facility (2014)

Two experimental areas (EAR):

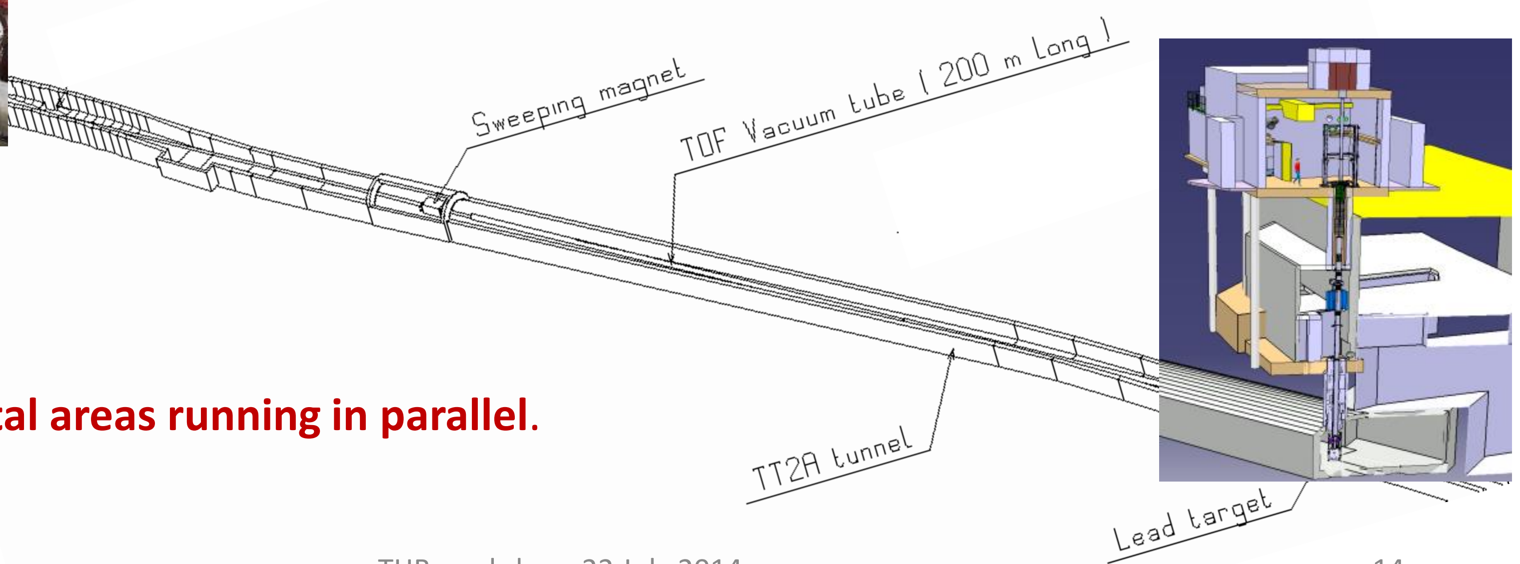
- Horizontal flight path:
  EAR1 at **182.5 m**
- Vertical flight path:
  EAR2 at **18.2 m**

Both beam lines have:

- 1st collimator:
  halo cleaning + first beam shaping.
- Filter station.
- Sweeping magnet.
- 2nd collimator: beam shaping.

EAR1

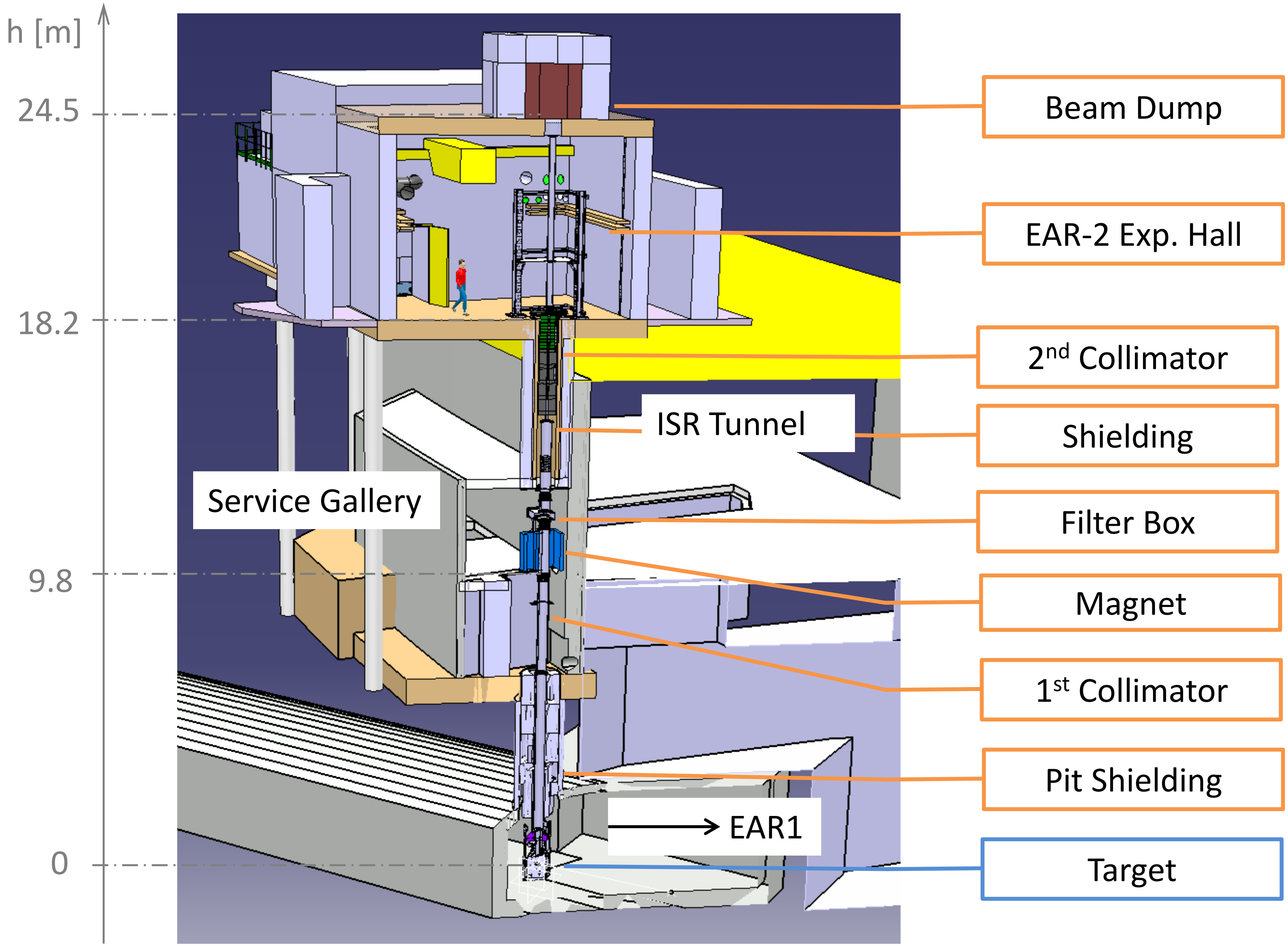
EAR2



Two experimental areas running in parallel.

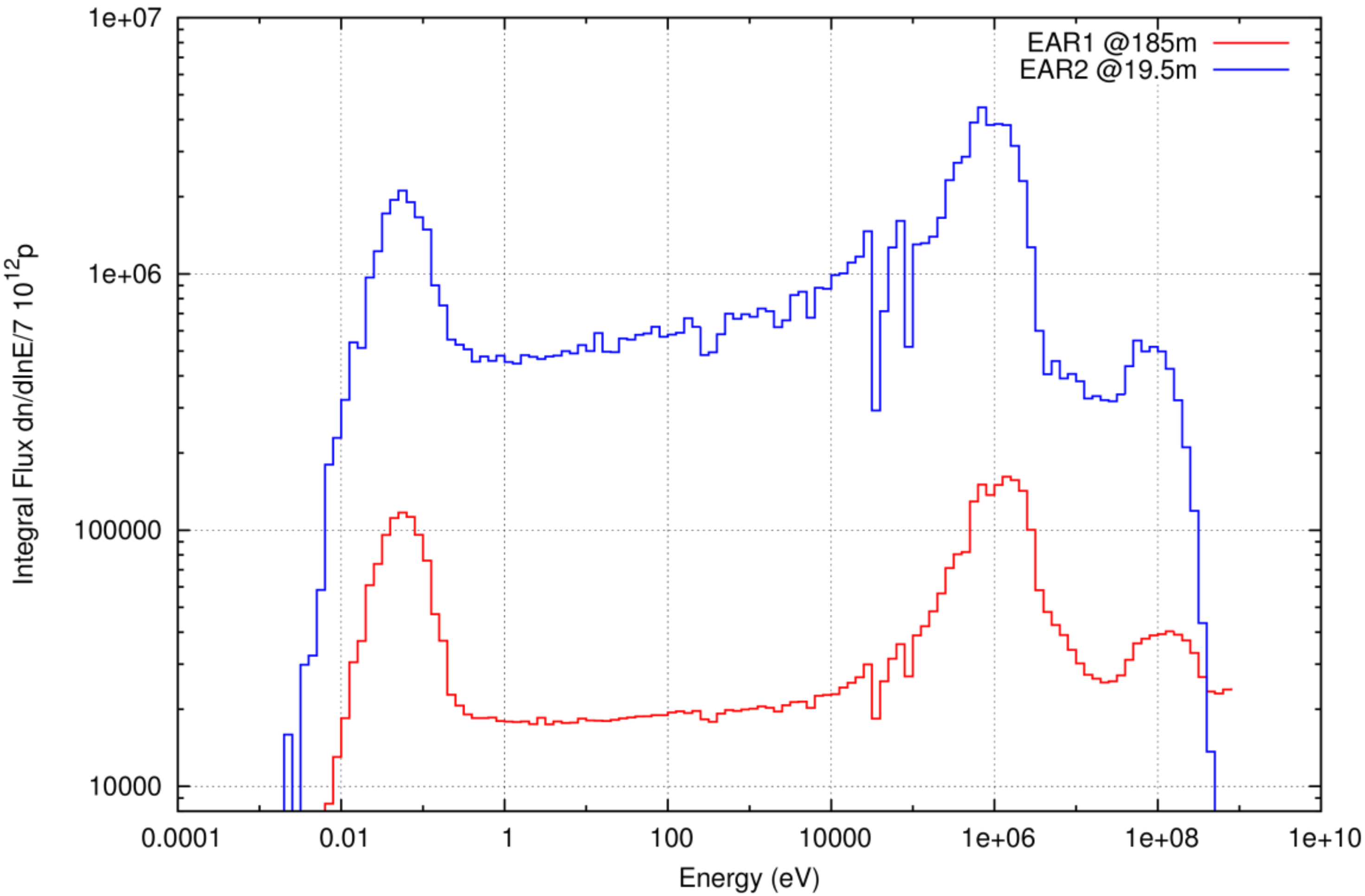
n_TOF EAR2 advantages

- Main advantages of Experimental Area 2:
  - Neutron fluence is on average increased by a factor of 25
  - Very small mass samples (<1 mg) could be measured
  - Very small cross-section
  - Much shorter time scale measurement (better signal-to-background ratio for radioactive samples)
  - Running in parallel with Experimental Area 1


h [m]
24.5
18.2
9.8
0
Beam Dump
EAR-2 Exp. Hall
2nd Collimator
ISR Tunnel
Shielding
Service Gallery
Filter Box
Magnet
1st Collimator
Pit Shielding
EAR1
Target


nTOF
nTOF
COMPLETED!

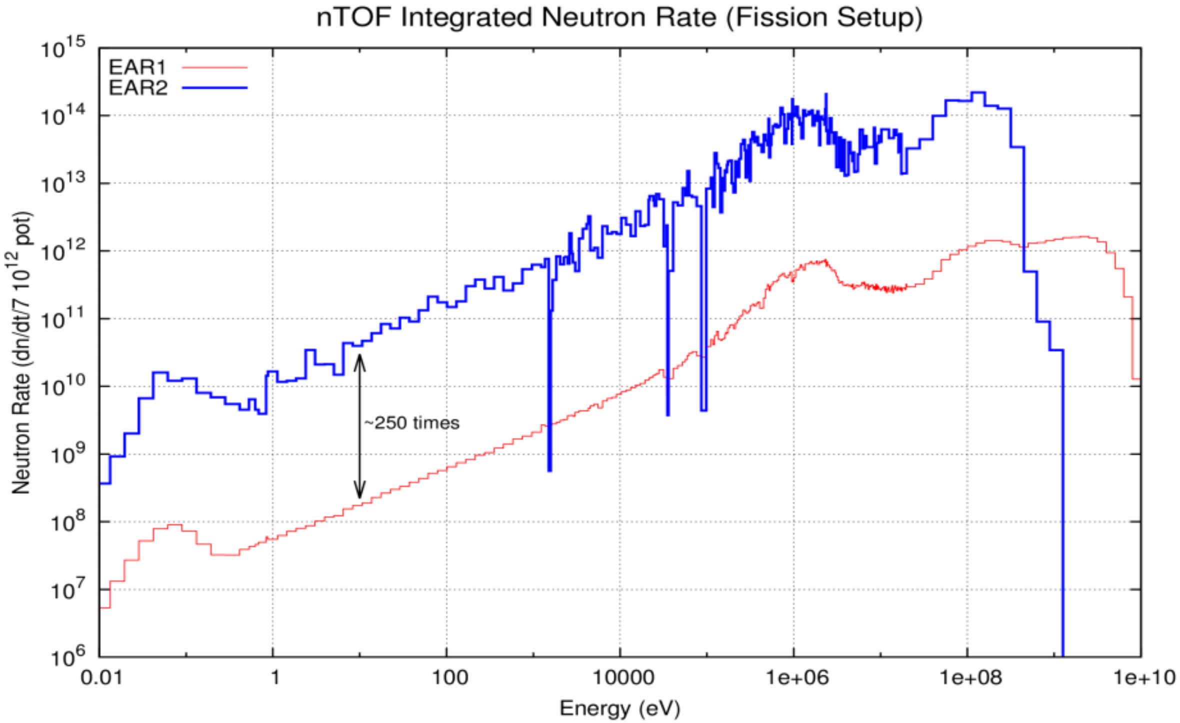
NEUTRON FLUX EAR1 vs EAR2



Neutron rate

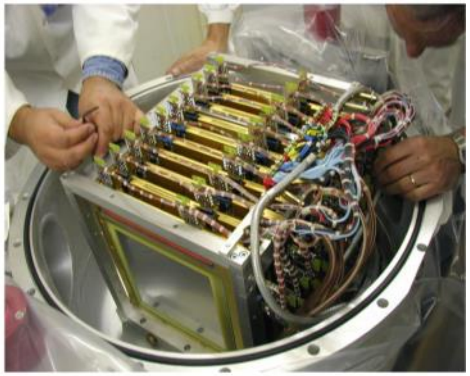
1. 25x higher fluence in EAR-2 wrt EAR-1
2. 10x times less alphas/gamma during neutron arrival

→250x times higher neutron rate

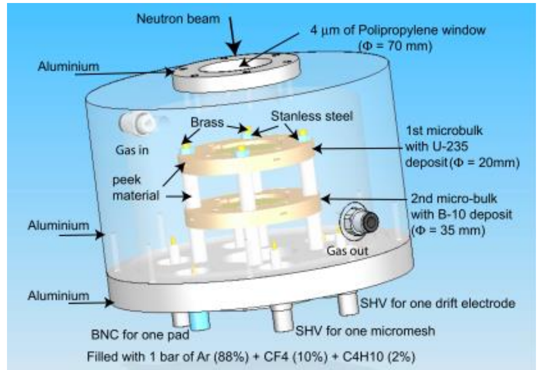


n_TOF Detectors

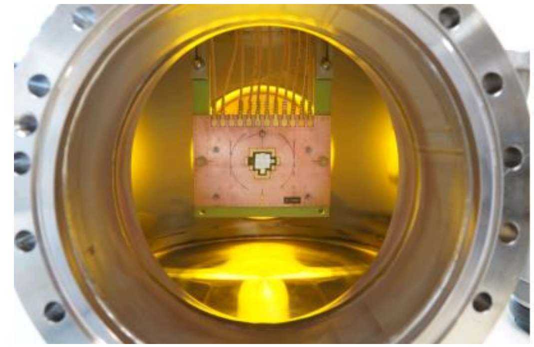
(n,chp) reactions



Parallel Plate Avalanche Counter (PPAC)

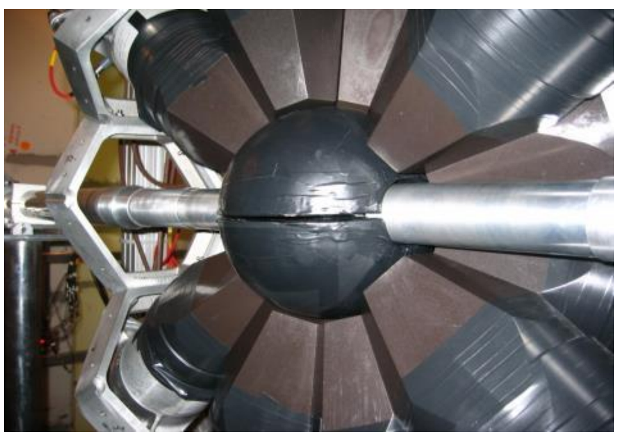


MicroMegas (MGAS)

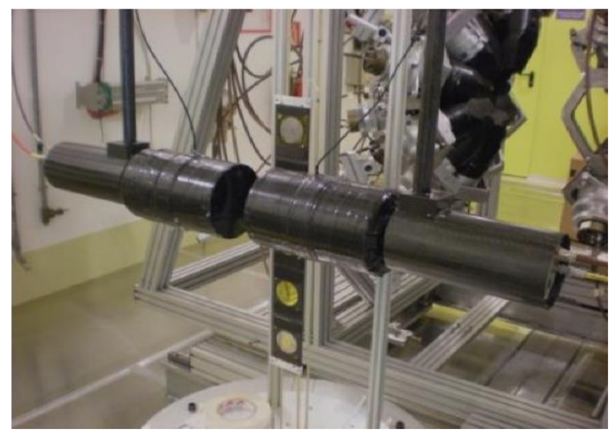


The Diamond-Mosaic Detector

(n,xnγ) reactions

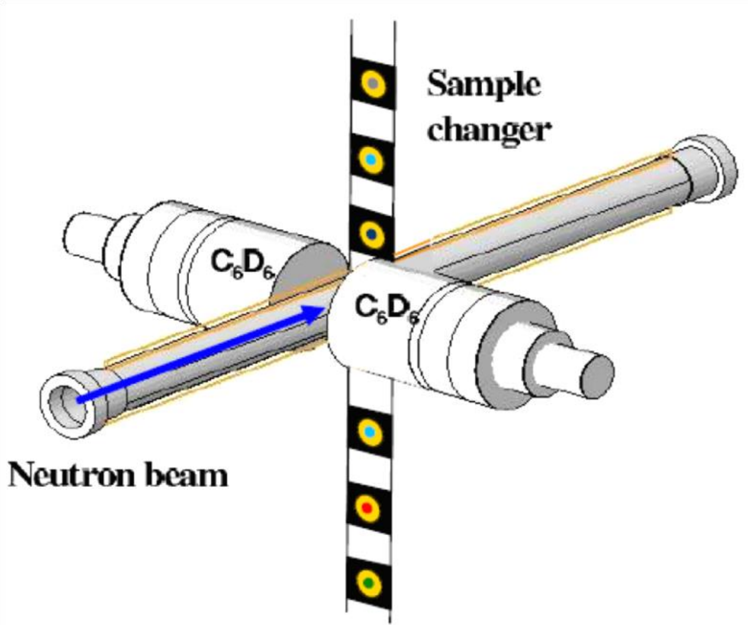


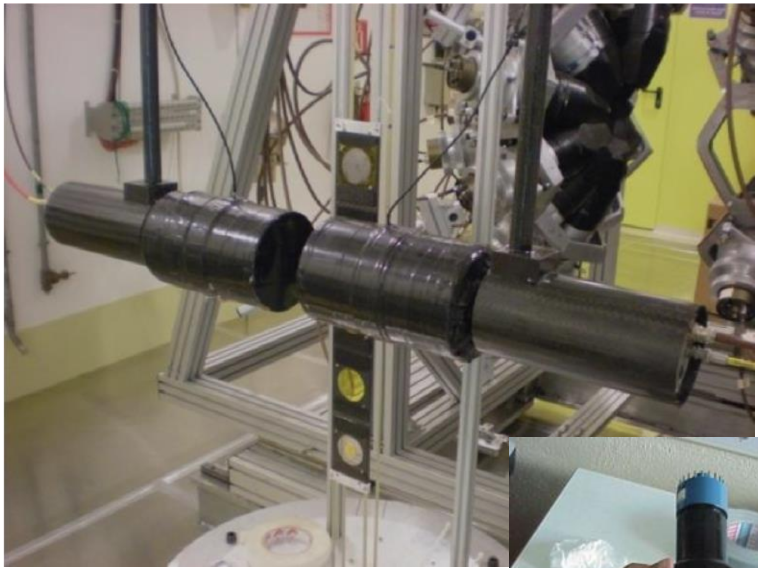
BaF_2 Total Absorption Calorimeter (TAC)



Low neutron sensitivity C_6D_6

Detectors with low neutron sensitivity

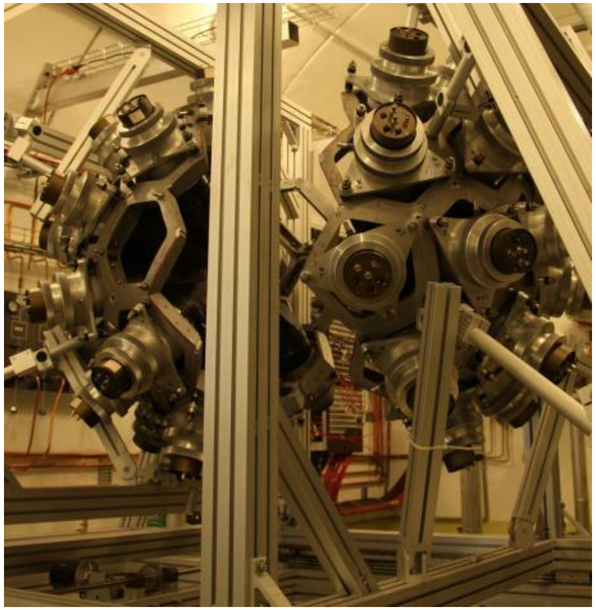


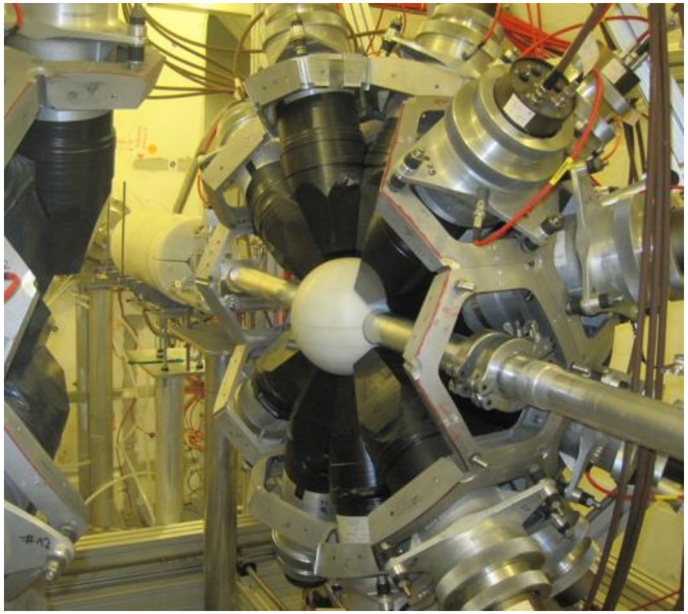


- At n_TOF neutron sensitivity enormously reduced relative to past detectors
- Very small amount of material and extensive used of carbon fibers
- However: low efficiency and selectivity

The n_TOF calorimeter

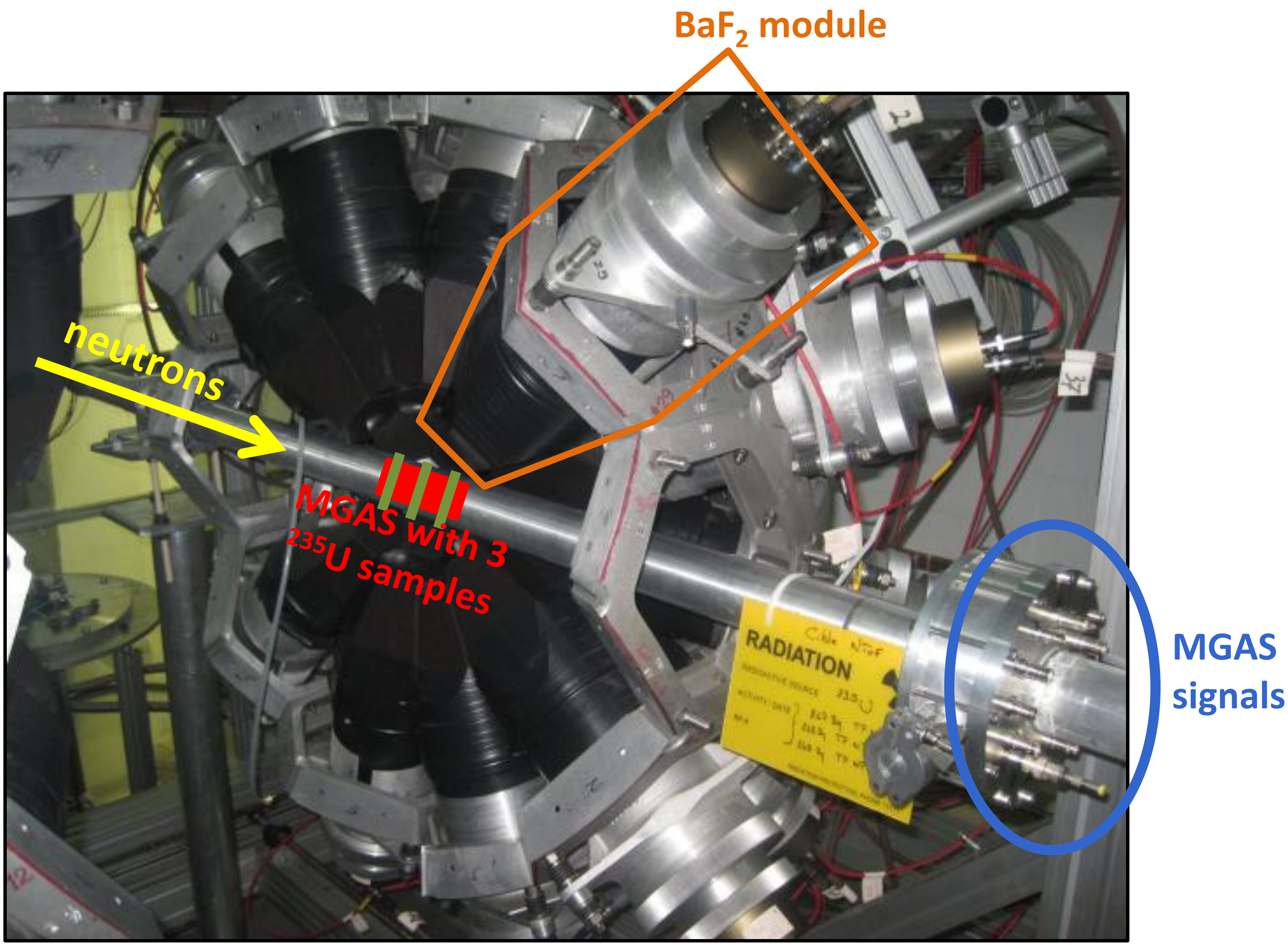
- n_TOF TAC:
  - 4π array of 40 BaF_2 scintillators (15 cm thick)
  - High efficiency allows to reconstruct the entire de-excitation cascade





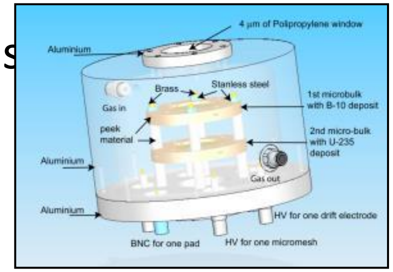
- High neutron sensitivity (detectors and heavy support structure)
  - Minimize neutron sensitivity with inner sphere of absorbing material and capsules in carbon fibre with ^{10}B

Simultaneous capture and fission of ^{235}U



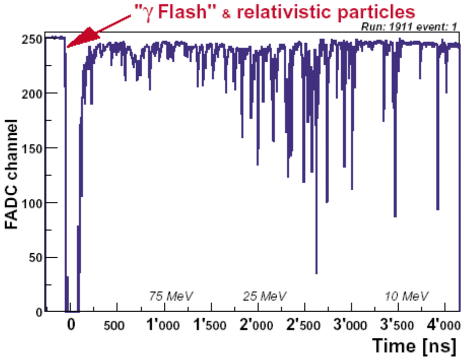
The fission setups

- The main problem in fission measurements is the **background due to α-decay**
- At n_TOF minimized by the very high instantaneous neutron flux
- Three different detectors employed:
  - Fission Ionization Chamber (FIC) [2002-2005]
    - Standard detector, with fast gas ($Ar+CF_4$) and electronics
  - Parallel Plate Avalanche Counters (PPAC) [2001-20xx]
    - Fission fragments detected in coincidence
    - Very good rejection of α-background
  - MicroMegas detector (MGAS) [2010-20xx]
    - Innovative detector based on the micro-mesh concept
    - In beam monitoring, no sensitivity to γ-rays, fast respons compact device, etc…



n_TOF Data Acquisition System

- High instantaneous neutron flux
  - Several events for each neutron pulse expected + pile-up between
- Standard DAQ methods are largely inadequate



- n_TOF DAQ based on **flash-ADC**:
  - ~50 fADC channels, up to 1 GS/s
  - Full history of every detector digitized during time window of up to 80 ms
  - Nearly zero dead time
- Offline signal reconstruction for time and charge
  - Pulse-shape fitting analysis (pile-up)
  - Simple algorithm for single signals

Conclusions

- There is need of **accurate new data** on neutron cross-section both for astrophysics and nuclear technology
- Since 2001, n_TOF is contributing to the **world efforts** aimed at collecting high quality data, mostly on capture and fission
- Main advantage of n_TOF is the **high instantaneous neutron flux** and **high performance detectors**
- **Improved background conditions** in EAR1 with the borated water system
- Radioprotection issues solved by transformation of EAR1 in a Work Sector Type A
- The **2nd experimental area (EAR2)** will open new perspectives for measurement with lower masses (ready by 2014)

Thank you for your attention!

Scientific Motivations

- Nuclear Waste Transmutation
- Astrophysics
- Medical Physics

Require the complete and precise knowledge of neutron cross sections

The n_TOF activity

Capture

^{151}Sm

^{204,206,207,208}Pb, ^{209}Bi

^{24,25,26}Mg

^{90,91,92,94,96}Zr, ^{93}Zr

^{186,187,188}Os, ^{139}La

^{232}Th, ^{233,234}U

^{237}Np, ^{240}Pu, ^{243}Am

Fission

^{233,234,235,236}U

^{232}Th, ^{209}Bi

^{237}Np

^{241,243}Am, ^{245}Cm

n_TOF phase 1 (2002-2004)

– **Measurements of capture reactions:**
  - **25 Isotopes** (8 of which radioactive)
  - Often of double interest (Astrophysics and applications)
  - Several publication

– **Measurements of fission cross-sections**:
  - **11 isotopes** (10 radioactive)
  - mainly linked to **Th/U cycle and transmutation**
  - **strong interest** by International Nuclear Agencies
  - results are still being published

EC Contracts

FP5: n-TOF-ND-ADS **FP6: EUROTRANS** **FP7: ANDES**

40 articles, 100 Conference Proceedings, 26 PhD thesis

The n_TOF activity

Capture

^{25}Mg, ^{54,56,57}Fe

^{58,60,62}Ni, ^{63}Ni, ^{88}Sr

^{236,238}U

^{241}Am

Fission

^{240,242}Pu

^{235}U(n,γ/f)

^{232}Th , ^{234}U, ^{237}Np ang. distr.

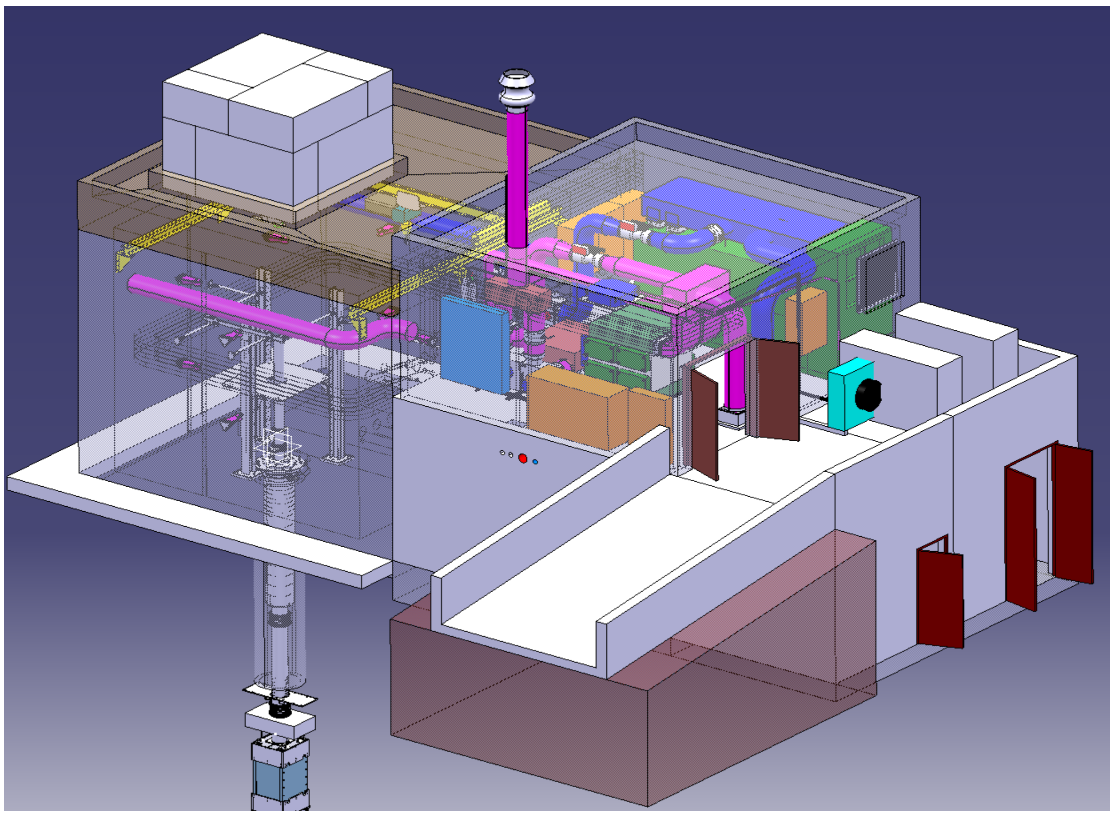
(n,α)

^{33}S, ^{59}Ni

n_TOF Phase 2 (2008-2012)

- **Measurements of capture reactions:**
  - **12 Isotopes** (4 of which radioactive)
  - Astrophysics and Nuclear Technology (transmutation)
- **Measurements of fission cross-sections**:
  - **6 isotopes** (5 radioactive)
  - Mainly for Nuclear Technology (ADS, Gen IV, Th/U cycle)
- **Other measurements**:
  - Simultaneous capture and fission
  - (n,a) reactions (using diamond detectors)

Experimental Area 2 (EAR2)

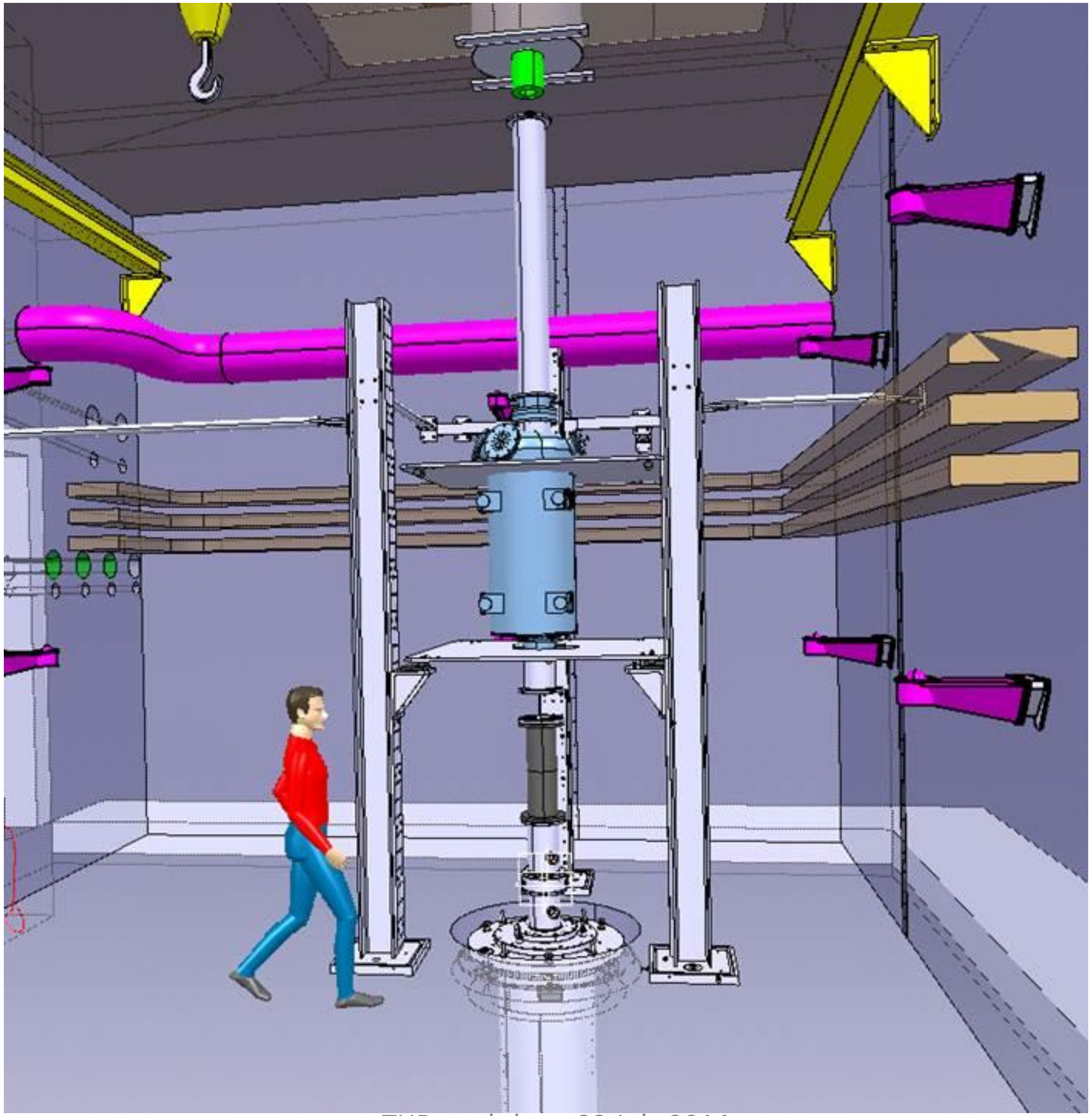


Neutron Fluence Comparison to EAR1

Energy Interval	EAR1		EAR2		Gain
	[n / cm^2 / pulse]	Error [%]	[n / cm^2 / pulse]	Error [%]	
0.02 – 10 eV	1.07e5	0.2	1.64e6	2.0	15.4
0.01 – 1 keV	3.98e4	0.3	1.07e6	1.4	26.8
1 – 100 keV	5.02e4	0.2	1.36e6	1.3	27.0
0.1 – 10 MeV	1.76e5	0.1	3.00e6	0.9	17.1
10 – 200 MeV	4.15e4	0.3	4.78e5	2.0	11.5
Total Range (0.02 eV – 200 MeV)	4.14e5	0.08	7.54e6	0.6	18.2

Reference for EAR1 : FLUKA Simulations with fission collimator (d = 8 cm)

Sketch of possible installation of Detectors



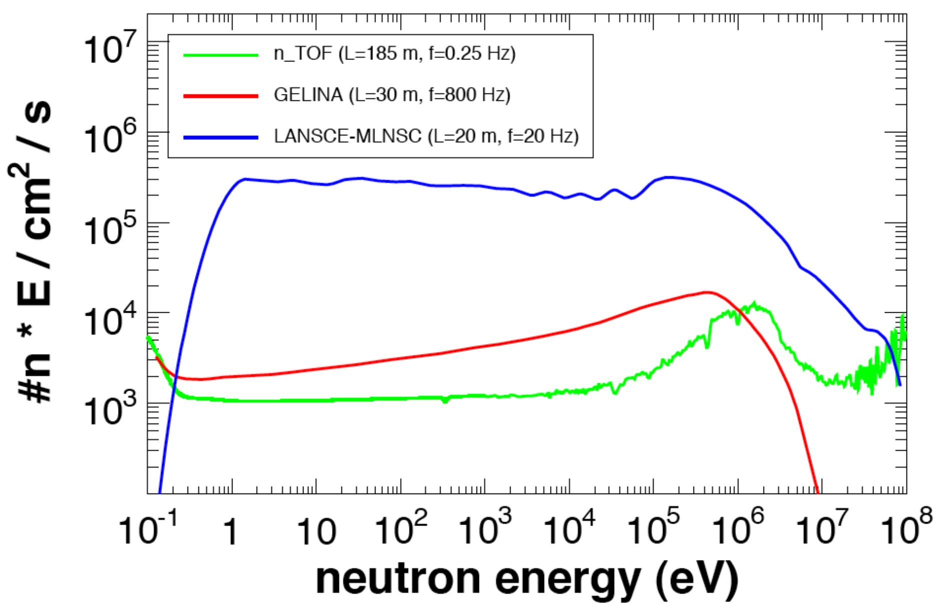
Comparing some neutron time-of-flight facilities

Facility	Location	Particle	Beam energy (MeV)	Neutron target	Pulse width (ns)	Beam power (kW)	Pulse frequency (Hz)	Flight path lengths (m)	Neutron production (n/pulse)
RPI	RPI, Troy, USA	e-	60	Ta	5	0.6	500	15–250	3.6×10^{9}
		e-	60	Ta	5,000	>10	300	15, 25	4.8×10^{11}
ORELA	ORNL, Oak Ridge, USA	e-	180	Ta	2–30	60	12–1,000	9–200	1×10^{12}
GELINA	EC-JRC-IRMM, Geel, Belgium	e-	100	U	1	10	40-800	5–400	4.3×10^{10}
nELBE	FZD, Rossendorf, Germany	e-	40	L-Pb	0.01	40	500,000	4	5.4×10^{7}
IREN	JINR, Dubna, Russia	e-	30	W	100	0.42	50	10–750	7.7×10^{10}
PNF	PAL, Pohang, Korea	e-	75	Ta	2,000	0.09	12	11	1.7×10^{10}
KURRI	Kumatori Japan	e-	46	Ta	2	0.046	300	10, 13, 24	2×10^{9}
		e-	30	Ta	4,000	6	100	10, 13, 24	8×10^{10}
LANSCE-MLNSC	LANL, Los Alamos, USA	p	800	W	135	80	20	7–60	7×10^{14}
LANSCE-WNR	LANL, Los Alamos, USA	p	800	W	0.2	1.44	13,900	8–90	8×10^{9}
n_TOF	CERN, Geneva, Switzerland	p	20,000	Pb	6	10	0.4	185	2×10^{15}
MLF-NNRI	J-PARC, Tokai, Japan	p	3,000	Hg	1,000	1,000	25	30	1.2×10^{17}

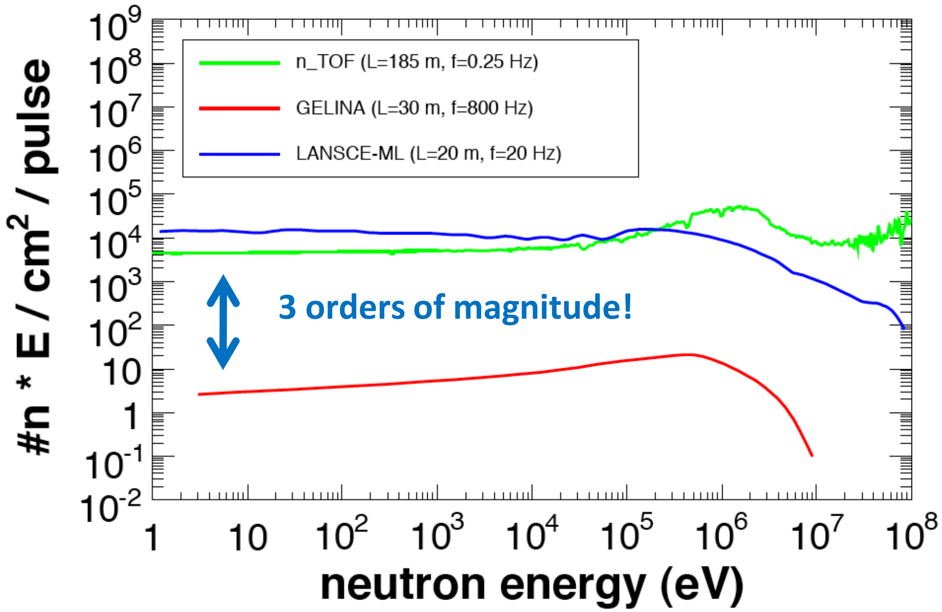
From: D. G. Cacuci (ed.), Handbook of Nuclear Engineering,
R. C. Block, Y. Danon, F. Gunsing, R. C. Haight
Chapter: Neutron Cross Section Measurements

n_TOF basic characteristics

Average flux (n/sec)



Instantaneous flux (n/pulse)



- n_TOF average flux comparable to GELINA (with 30 m flight path)

- Very high instantaneous neutron flux
  - High proton intensity per pulse
  - Spallation process

- Great advantage in measuring radioactive samples (improved S/N ratio)

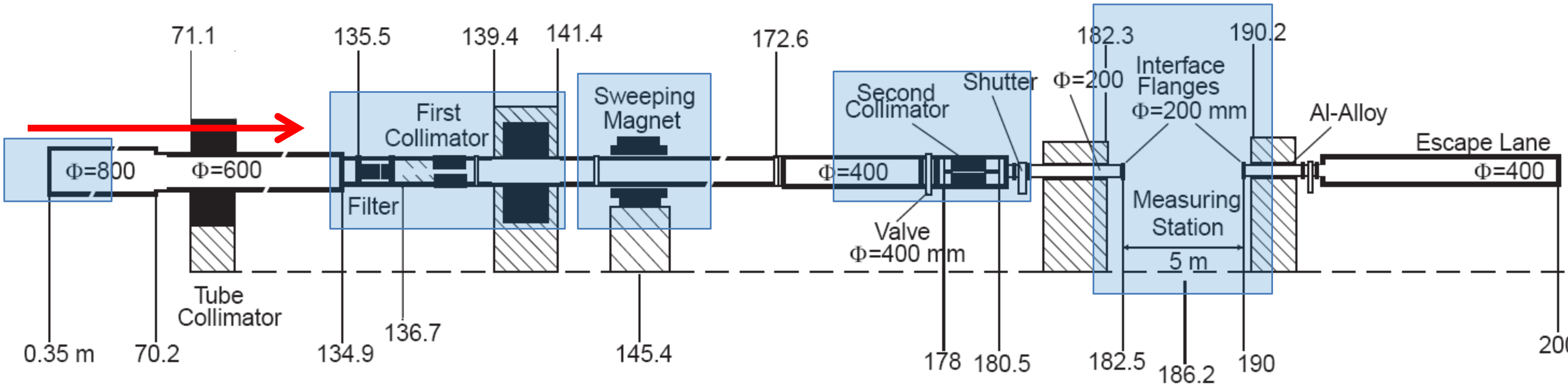
PROPOSAL EAR1

n_TOF EAR1 Proposal Document #	Field of interest	Year
Re-commissioning of n_TOF EAR1 CERN-INTC-2014-008 / INTC-P-407	Commissioning	2014
Neutron capture at the s-process branching points 171Tm and 204Tl CERN-INTC-2014-003 / INTC-P-404	Astrophysics	2014
Radiative capture on 242Pu for MOX fuel reactors CERN-INTC-2013-027 / INTC-P-387	Nuclear Tech.	2014
Winter SHUTDOWN		
Neutron capture cross sections of 70;72;73;74;76Ge at n TOF EAR-1 CERN-INTC-2013-021 / INTC-P-381	Astrophysics	2015
Measurements of neutron induced capture and fission reactions on 233U CERN-INTC-2013-041 / INTC-P-397	Nuclear Tech.	2015
35Cl(n,p)35S for NCT *To be proposed (LOI Feb. 2014)*	*Medical App.*	*2015*
High accuracy measurement of the 235U(n,f) reaction XS in the 10-30 keV neutron energy range	*Nuclear Tech.*	*2015*
Total # of protons (all proposals)		

PROPOSAL EAR2 from 2014

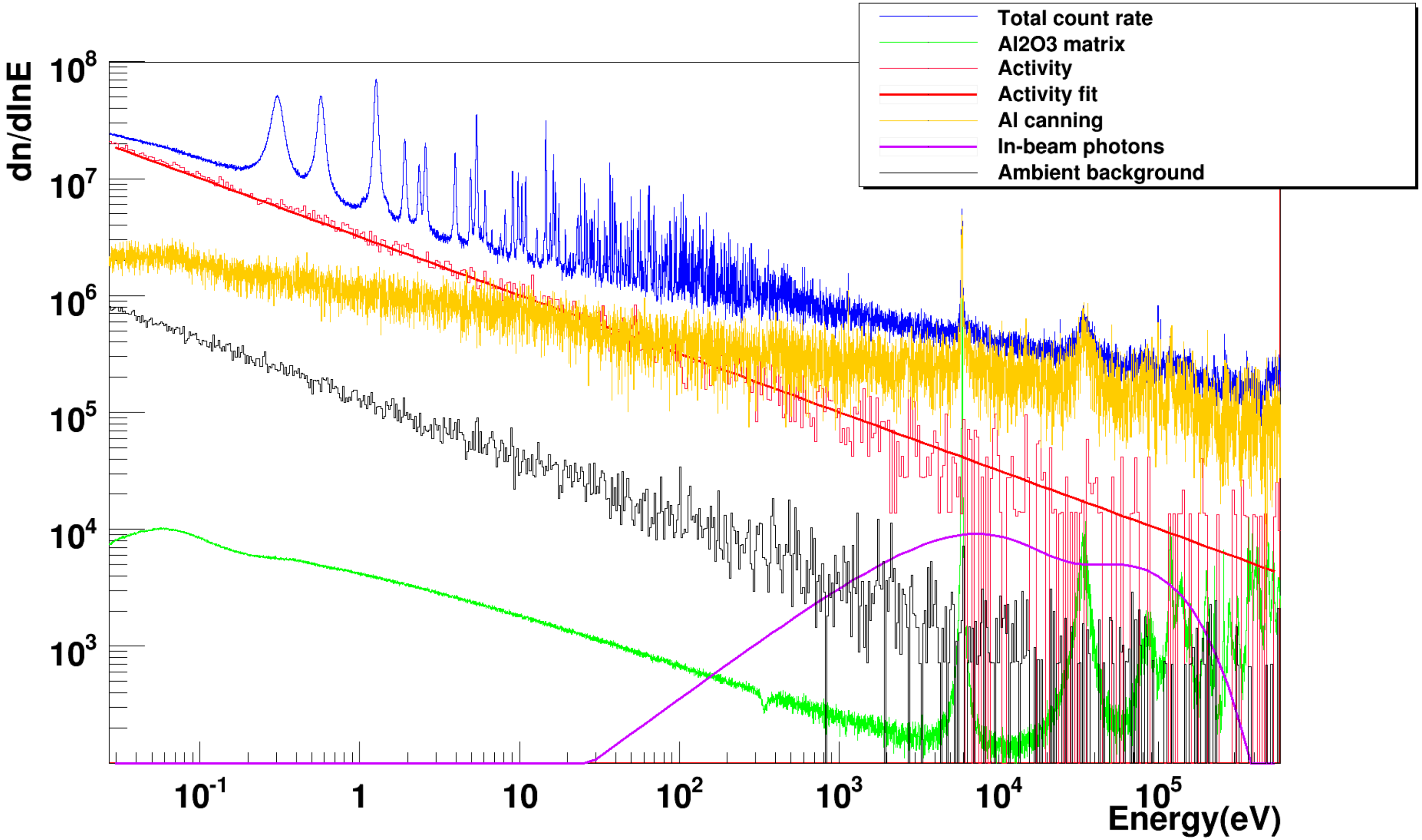
n_TOF EAR2 Proposal Document #	Field of interest	Year
Commissioning of n_TOF EAR2 CERN-INTC-2013-043 / INTC-P-399	Commissioning	2014
γ-ray Energy Spectra and Multiplicities from the Fission of 235U using STEFF CERN-INTC-2014-004 / INTC-P-405	Nuclear Tech.	2014
Winter SHUTDOWN		
Measurement of the neutron capture cross-sections of 53Mn at EAR-2 CERN-INTC-2014-012 / INTC-P-408	Astrophysics	2015
Destruction of the cosmic γ-ray emitter 26Al by neutron induced reactions CERN-INTC-2014-006 / INTC-P-406	Astrophysics	2015
Neutron capture at the s-process branching point 147Pm *To be proposed*	*Astrophysics*	*2015*
14N(n,p)14C for NCT *To be proposed (LOI Feb. 2014)*	*Medical App.*	*2015*
Measurement of the 240Pu(n,f) reaction cross-section at the CERN n_TOF facility EAR-2	*Nuclear Tech.*	*2014*
Measurement of 7Be(n,a)4He and 7Be(n,p)7Li cross sections for the Cosmological Lithium Problem	*Astrophysics*	*2015*
Feasibility of the (n,γ) on 235U and 239Pu with a fission tagging C6D6 setup *To be proposed*	*Nuclear Tech.*	*2015*
The (n,α) reaction cross section measurement for light isotopes *To be proposed*	*Basic Physics*	*2015*
Helium production in tungsten relevant to divertors in future fusion reactors *To be proposed*	*Nuclear Tech.*	*2015*
Total # of protons (all proposals)		

n_TOF experimental setup



- Spallation target → neutrons
- 1st collimator (Ø=11 cm)
  - Halo cleaning, first shaping of the beam + filter station
- Sweeping magnet
- 2nd collimator (Ø=1.8/8 cm) – beam shaping for EAR
- Experimental Area 1
  - 186 m from spallation target, location of samples and detector

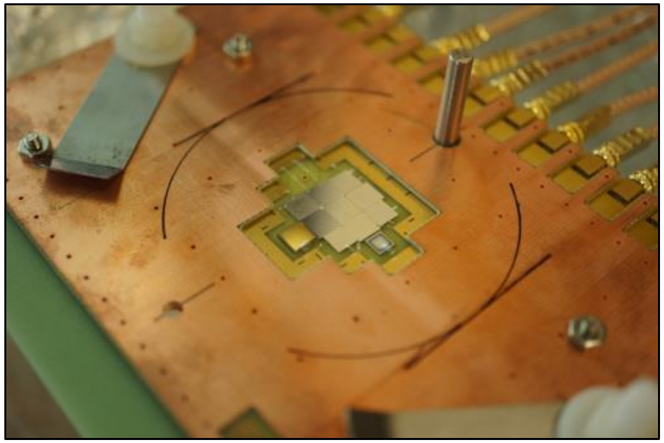
^{241}Am (n,γ) data (C_6D_6)

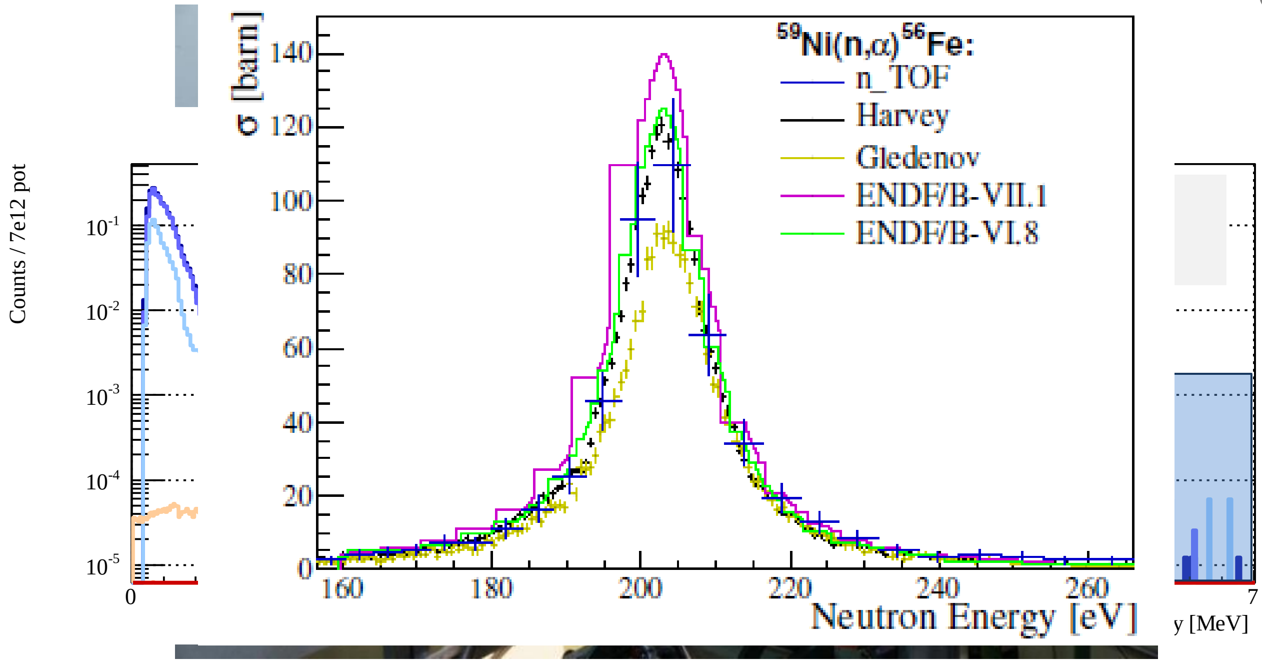


New development

Array of 9 sCVD diamond diodes:

1. Thickness: 150 μm
2. Detector size 5x5 mm^2 (each)
3. Electrodes: 200 nm Al





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